is to be his course of study in between? Before the advanced treatise, or at any rate, such a one as Dr. Marr would approve, can be really entered on and appreciated, the student must surely have some practical acquaintance with carbon dioxide and silica as chemical substances, with "boneless animals" and "those possessing bones," and with other matters that are here mentioned as if they were absolutely new to his intelligence. On pp. 224 and 225 the beginner is sent out into the open country as his "true museum." This is excellent advice for the true beginner in geology, but not for those beginners in science whom Dr. Marr, from his experience of English public schools, finds himself compelled to contemplate.

Among the excellent points in the present treatise we notice the early introduction of conceptions of crust-movement, which render descriptions of other phenomena far more easy of comprehension; the reference to what is often known as "plucking" in the action of glaciers (p. 57); and the concise account of plains of denudation (peneplains) on p. 99. Among the very few slips, we may note that Kimeridge (p. 179) is in Dorset, not in Wiltshire; that the insoluble part of felspar (p. 79) does not by itself form china-clay; and that the phrase "evaporation of water by the sun" (p. 67) is scarcely a happy one. The fan-structure on p. 93 is, we think, not that usually thought of in connection with the term.

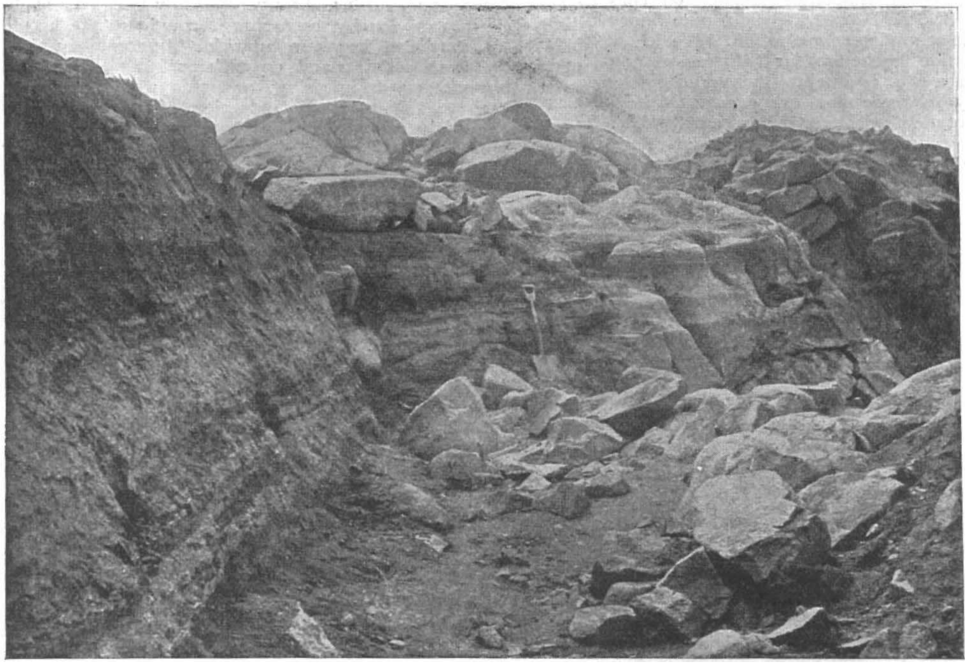

FIG. 1.—Wind-worn surface of older rocks (on right), revealed by removal of New Red Sandstone, Charnwood Forest. Landscape of Triassic times. (From Marr's "Introduction to Geology.")

On p. 65 we must invoke subsidence of the crust to enable the sea to perform all the work there claimed for it; and we should like more sympathy on p. 89 with the view that the earth is continually losing moisture from its interior. Lastly, the author (p. 181) should not, even by an accident of phraseology, encourage a belief in the existence of "fossil thunderbolts." But these small asperities only give an edge to our appreciation. GRENVILLE A. J. COLE.

TIDAL RESEARCHES.[1]

ONE of the crowning features of the enunciation by Newton of the law of universal gravitation consisted in the fact that herein the phenomena of the tides and their relationship with the moon could for the first time be coordinated with other well-known phenomena of the solar system. Though the principal phenomena of rise and fall and ebb and flood of the sea must have been recognised by coast dwellers and navigators from the earliest times, the theory of the tides as it exists to-day may fairly be said to have originated with Newton, and its purpose has largely been to examine to what extent these phenomena are attributable solely to a gravitational cause or how far it may be necessary to invoke some other exciting or controlling influence.

It was early recognised that a theory which failed to take due account of the inertia of the water, of the earth's rotation, and of the curvature of its surface could but inadequately represent the phenomena actually existent in nature, and the reduction of the tidal problem to a mathematical form in which all these features were duly taken into account was first accomplished by Laplace; since his time the equations furnished by him have formed the basis of almost all attempts to further the study of the tides from its purely theoretical aspect. The theory of tides in narrow canals developed *in extenso* by Airy, though not directly based on Laplace's equations, consists largely in the discussion of a special type of solvable cases of the more general mathematical problem propounded by Laplace. In the memoirs under review the author emphasises the hopelessness of such attempts to realise their main purpose of providing a theory sufficiently exact and yet sufficiently general in character to allow of direct comparison with observations, as is the practice in the study of other gravitational phenomena such as the planetary motions, and proposes a new method of attacking the problem. An essential difference between this method and that of Laplace consists in the fact that in the former the influence of the earth's rotation is regarded as of secondary importance. Such solutions of Laplace's equations as have been obtained, which allow of an exact estimate of the

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[1] "A Manual of Tides." Part iv. A, Outlines of Tidal Theory. Part iv. B, Cotidal Lines of the World. By Rollin A. Harris. Appendices to Reports of U.S. Coast and Geodetic Survey.

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influence of the rotation in the restricted problems dealt with, by no means appear to justify this course.

If, however, a complete tidal theory which should adequately account for all the phenomena of observation has hitherto been found wanting, at least considerable advance in the coordination of observed phenomena has been obtained by the introduction of the harmonic analysis for the discussion of tidal observations, while tidal records suitable for such analysis have accumulated. These, so far as they are accessible at all, are scattered through various scientific publications, and the author has rendered a valuable service to all interested in tidal phenomena in collecting them in tabular form in a single memoir. The tables given on pp. 664–677, part iv. A, and pp. 342–351, part iv. B, contain the results of the harmonic analysis of tidal observations taken at more than four hundred stations distributed throughout the world, and probably contain almost all information of a precise character in relation to the tides at present available. These tables give the amplitudes and phases of the principal types of oscillation as derived from observation alone, and only involve theory in so far as it enables us to assign the periods in advance by means of exact astronomical data. It is to be regretted that in no case is any indication given of the degree of precision with which the analysed results reproduce the actual observations from which they are derived, or of the extent to which they confirm the theory on which they depend.

A considerable portion of the memoirs is further devoted to an attempt to coordinate the results derived from different stations so as to form a comprehensive picture of the general progress of the tide-wave over the surface of the ocean, and the results are exhibited in a series of charts indicating the position of the wave crest at each successive cotidal hour.

The construction of these charts is, unfortunately, but vaguely indicated. As already stated, no ready means is provided of estimating the value of the material used for the purpose, or of the methods used for its combination.

In so far as these charts are based on the results of observation alone we are prepared to believe that they give a fairly accurate representation of the actual tides in the regions where observations are sufficiently numerous to supply the necessary information, but, as is well indicated in the cotidal chart due to Berghaus and reproduced by the author, there will remain very considerable tracts of the ocean surface about which no observational information is available, and which are left blank on the charts prepared by Berghaus. In fact, as tidal observation is almost of necessity confined to the neighbourhood of the coast lines, the only method of filling in such blanks is to have recourse to theory, and the correctness or otherwise of the charts prepared by the author must therefore depend to a very considerable extent on the correctness of the theory which he has put forward, which forms the principal subject of Part iv. A.

This theory has already been the subject of adverse criticism in NATURE (September 4, 1902, p. 444), and we cannot but regret that we have to adhere to the objections to it previously raised.

Without reverting to these objections it is rather our purpose here to examine the particular applications of it now dealt with in part iv. B, which constitute the chief purpose for which it was designed. The object of the author, as he himself expresses it, is "to obtain through theoretical considerations . . . a first approximation to the times of the principal ocean tides," *i.e.* the phases of the oscillations in relation to those of the disturbing forces which produce them. The times in question are deduced from a theorem based on the analogue of the compound pendulum which asserts that in maintained simple harmonic motion under the action of friction "the virtual work of the external periodic forces is zero at the instant of elongation." If we rightly understand the significance of this theorem, it would appear to imply that, at the instant of elongation, the disturbing forces which give rise to the type of motion under consideration form an equilibrium system. We conclude either that they are in equilibrium throughout the motion or that they are in equilibrium at this instant in virtue of the fact that their resultant, which is *ex hypothesi* of a simple harmonic character, is passing through its zero phase. The former hypothesis may be dismissed as giving rise to no permanent oscillation; the latter indicates a phase difference of a quarter of a period between the phase of the oscillation and that of the resultant disturbing force.

The application of the theorem in question to the tidal problem is somewhat obscure, but the illustration of the simple pendulum presented by the author enables us at once to recognise an essential condition under which it is applicable. The phase difference in this case is correctly expressed by equation (297), which indicates in general a phase difference of zero or half a period when friction is slight. When, however, friction is sufficiently great the phase difference may amount approximately to a quarter of a period, and the same will be true even with small friction when there is an exact coincidence between the period of the disturbing force and the "natural" period of vibration of the pendulum.

Thus the fundamental theorem on which the determination of the phase depends only holds good if we regard friction as sufficiently large to control the phase, and unless the relative influence of friction in comparison with other causes which influence the phase is in some way known, the phase will remain quite indeterminate. Of course it may be contended that in the case of the tides the conditions necessary to render friction the controlling factor exist, but this contention is nowhere put forward explicitly by the author, and we are of opinion that it could not be substantiated. We are further of opinion that the effects of friction on phase will be everywhere comparatively insignificant, so that we should expect to find the phases of the oscillations, so far as they can be resolved into separate simple harmonic types, approximately in agreement with (or differing by half a period from) those of the disturbing causes instead of, as the author's theory requires, differing from them by a quarter of a period. We conclude that the author's theory ceases to be available even to lead to a "first approximation" in the determination of the phases.

We can thus only regard the charts produced, except in so far as they are controlled by direct observations, as a speculation on the part of the author unsupported by scientific evidence, and regret that an otherwise painstaking and far-reaching research on our existing knowledge of the tides has been marred by the intervention of an unsatisfactory theory which we feel bound to regard as not merely inadequate, but for the purposes to which it is applied actually misleading.

S. S. H.

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